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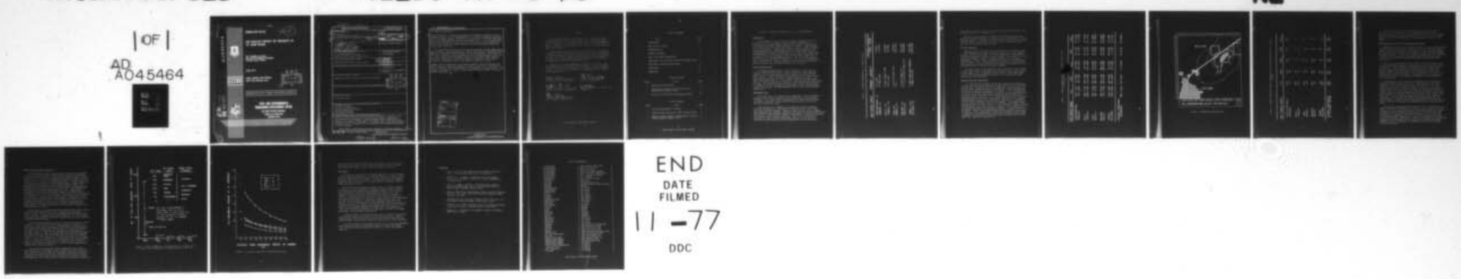

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AIR QUALITY IMPACT OF AIRCRAFT AT 10 USAF BASES

DET 1 (CEEDO), HQ ADTC
AIR QUALITY RESEARCH DIVISION
TYNDALL AFB, FL 32403

APRIL 1977

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FINAL REPORT FOR PERIOD
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CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
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TYNDALL AIR FORCE BASE
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The contributions of Air Force aircraft to ambient air quality at 10 major bases were predicted from operational data using a computerized Gaussian dispersion technique. Annual arithmetic mean concentrations are presented for common air pollutants. The predictions are well below National Ambient Air Quality Standards for those pollutants with standards specified as annual averages.

Hourly "worst case" predictions were converted to Pollutant Standards → over

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20. Abstract (concluded)

Index (PSI) values. Aircraft sources produced average PSI values of 4.9 for nitrogen dioxide, 2.1 for carbon monoxide, 1.9 for total suspended particulates, and 1.4 for sulfur dioxide. The PSI scale ranges from 0 to 500 with 100 designated as the level above which health effects may occur. A PSI for hydrocarbons could not be computed since direct health effects have not been observed and indirect effects through oxidant formation could not be predicted within the scope of this analysis.

Air Force emission goals have been adopted for future turbine engine development programs. Under present policy, engine modifications or retrofit programs depend on a demonstrated environmental need for such measures. The results of this effort, with the possible exception of those for hydrocarbons, do not seem to indicate significant environmental benefits from further control measures. Hydrocarbon controls may or may not be suggested, depending on the complex photochemical reactions in each of the regions around the air bases.

The relative significance of pollutants emitted by AF aircraft indicated by this report is (from most significant to least significant): hydrocarbons, oxides, or nitrogen, particulate matter, carbon monoxide, and sulfur oxides. This ordering can be used as a guide to future engine design priorities and control strategy development.

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PREFACE

This technical report is a duplicate of Air Pollution Control Association Paper 77-41.6, to be presented at the Annual APCA Meeting on 23 June 1977. The technical work for this effort was performed under the auspices of the Air Force Civil Engineering Center (AFSC), which, on 8 April 1977, reorganized into Detachment 1 (CEEDO) HQ ADTC, Tyndall AFB, Florida.

Captain Dennis F. Naugle was project engineer and author; Majors Bradford C. Grems III and Peter S. Daley were coauthors. Development of computerized data reduction subroutines was performed by Lieutenant Harold A. Scott. Major contributions were also made by Lieutenant S. C. Enzweiler and Master Sergeant Richard Dalrymple who performed the Air Quality Assessment Model computer runs.

This report has been reviewed by the Office of Information and was cleared for open publication by DoD (OASD-PA) on April 19, 1977. It will be distributed by the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

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AIR QUALITY IMPACT OF AIRCRAFT AT 10 U.S. AIR FORCE BASES

Introduction

The Department of the Air Force has adopted quantitative goals for the control of aircraft engine exhaust emissions (Reference 1). A balance has been sought between important environmental considerations and essential safety and combat effectiveness criteria. Specific goals are set for oxides of nitrogen (NO_x), smoke, carbon monoxide, and hydrocarbons (Reference 2). These goals apply to turbofan, turbojet, and turboprop engines beginning development after 11 June 1975. Engines in development prior to that time and still in substantial production after 1 January 1979 will be modified or retrofitted to reduce emissions if justified by cost and environmental studies. The aim of this research is to investigate the impact of current Air Force aircraft operations on the local air quality. The environmental need for additional aircraft emission controls can, in part, be based on this analysis.

The Air Quality Model

The computerized model used for this analysis is called the Air Quality Assessment Model (AQAM). AQAM is comprised of four component programs: Source Inventory, Short-Term, Long-Term and Meteorological Data. Source Inventory combines aircraft operational data with measured engine emission factors to produce an annual emissions inventory. The Short-Term program predicts 1-hour average concentrations under meteorological conditions specific to that hour. Gaussian dispersion subroutines are used. The Long-Term program predicts annual average concentrations by combining aircraft emissions and climatological data from the Meteorological Data program. All AQAM components are fully described elsewhere (Reference 3).

Operational Data

Air Force bases can be functionally categorized as tactical fighter, strategic bomber/tanker, transport, flying training, or major overhaul facilities. Ten installations representing all of these activities are included in this study. Annual aircraft operations data for each air base are presented in Table 1.

Each air base was visited by a field team from Stanford Research Institute (Reference 4). Operational records were used as the primary data source whenever possible. Extensive interviews with pilots, maintenance personnel and operations supervisors also provided detailed descriptions of ground and flight profiles, temporal distributions of aircraft operations and aircraft service vehicle operations. These data, combined with a comprehensive engine emission measurement program, are the building blocks for detailed emission profile modelling for each aircraft type.

TABLE 1. AIRCRAFT OPERATIONS AT 10 BASES STUDIED

AIR FORCE BASE	PRIMARY AIRCRAFT	LANDINGS + TAKEOFFS PER YEAR
DAVIS-MONTHAN, AZ.	A-7, T-33	57,800
GRISSOM, IN.	KC-135, A-37	19,648
KELLY, TX.	C-130, F-100, T-38	29,608
LANGLEY, VA.	F-15, T-39	57,686
LUKE, AZ.	F-4, F-5, F-15, F-104	116,690
MacDILL, FL.	F-4	45,178
McGUIRE, NJ.	C-141, F-105, C-7	35,178
NELLIS, NV.	F-111, F-4, F-5, T-38, T-37	55,944
TINKER, OKLA.	T-38, F-105, mis. transports	35,252
WILLIAMS, AZ.	T-38, T-37, F-5	226,076

These specific profiles are more accurate than generalized profiles such as those of EPA's AP-42 (Reference 5).

The data in this study are current as of January 1976, with the exception of Langley AFB where the projected full complement of an F-15 wing was modelled. Emissions or impact at a specific base may be slightly different today, but the basic functional types of operations should still be well represented by these data.

Aircraft Emissions

Annual aircraft emissions for each location are presented in Table 2. Only emissions up to 3,000 feet above ground level in the immediate airport vicinity are included. Therefore, inferences concerning high altitude environmental questions cannot be made. The percent of aircraft emissions compared to regional emissions (Reference 4) is shown in parentheses. Average airbase contributions are less than 1 percent for all pollutants. Thus, regional impact on air quality is not indicated. Emission and air quality analyses in this effort will therefore focus on the possibility of localized air quality problems.

For the purpose of this study, all source emissions of total hydrocarbons (THC), oxides of nitrogen (NO_x), oxides of sulfur (SO_x) and particulate matter (PM) are assumed to yield reactive hydrocarbons (RHC), NO_2, SO_2 and total suspended particulates (TSP), respectively, when dispersed in the ambient air.

Annual Air Quality Predictions

The AQAM Long-Term program combines the temporal distributions of aircraft activity with the properly weighted combinations of wind speed and direction, atmospheric stability, temperature, and mixing depth to predict annual average pollutant concentrations. These concentrations are usually displayed as isopleths as in Figure 1. Such illustrations are useful in analyzing the impact of specific sources and pollutants at a given location, but do not permit simple comparisons among various pollutants at many locations. It was therefore necessary to choose consistent receptor criteria for a meaningful comparison of all 10 bases. Concentrations along 16 wind directions at a distance of 5 kilometers from the runway geographic centers were computed. The highest concentrations of each pollutant along any wind direction (the annual concentration indices) are shown in Table 3. The 5-kilometer downwind distance was arbitrarily chosen for comparative purposes. It does represent a reasonable compromise to avoid problems caused by receptors too close to the source. Steep concentration gradients and irregular profiles make it impossible to randomly select a point representative of the average conditions. At distances far from the source, concentrations become so small that comparisons are difficult.

TABLE 2. ANNUAL AIRCRAFT EMIS[illegible] METRIC TONS/PER YEAR
(% of Regional E[illegible])

AIR FORCE BASE	CO	THC	NO_x	PM	SO_x
DAVIS-MONTHAN	1600 (1.1%)	54 (0.1%)	30 (0.1%)	37 (0.1%)	27 (0.3%)
GRISSOM	890 (0.3%)	330 (0.5%)	180 (0.5%)	25 (0.1%)	19 (0.0%)
KELLY	3200 (1.2%)	460 (0.8%)	94 (02%)	33 (0.1%)	19 (0.1%)
LANGLEY	2000 (0.7%)	210 (0.4%)	290 (0.8%)	33 (0.0%)	23 (0.0%)
LUKE	1900 (0.3%)	290 (02%)	230 (0.3%)	43 (0.1%)	37 (0.9%)
MacDILL	890 (0.5%)	200 (0.5%)	130 (0.1%)	70 (0.2%)	23 (0.0%)
McGUIRE	1700 (0.8%)	1000 (2.7%)	380 (0.5%)	34 (0.3%)	44 (0.1%)
NELLIS	1100 (1.4%)	240 (2.1%)	200 (2.2%)	35 (0.1%)	23 (2.6%)
TINKER	1000 (0.3%)	360 (0.4%)	92 (0.1%)	26 (0.2%)	16 (0.3%)
WILLIAMS	4700 (0.8%)	1400 (0.9%)	120 (0.2%)	11 (0.0%)	54 (1.3%)
AVERAGE EMISSIONS- AVERAGE %	1898 (0.7%)	454 (0.9%)	175 (0.5%)	35 (0.1%)	29 (0.6%)

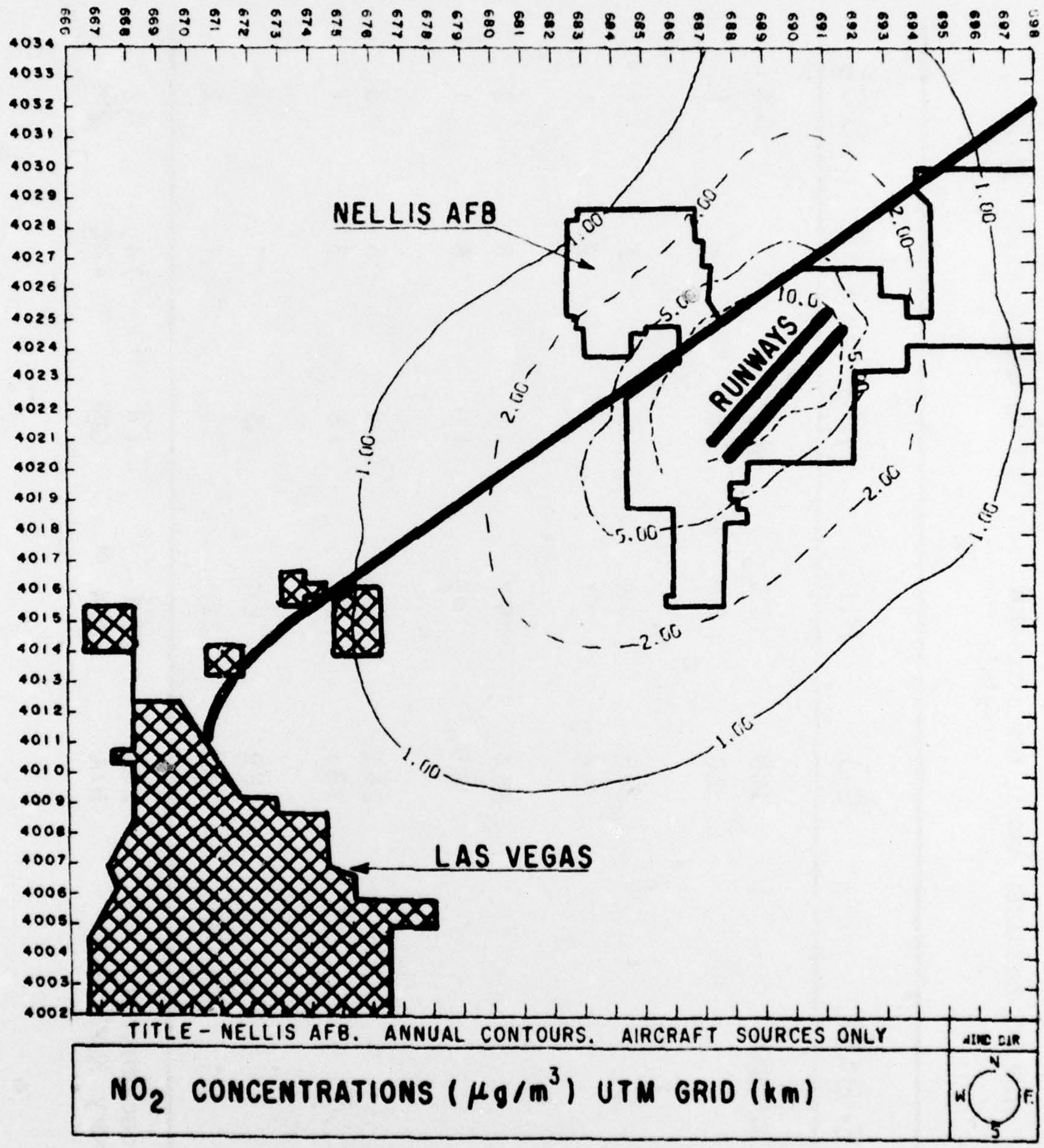

Figure 1. Annual NO_2 Concentrations

TABLE 3. HIGHEST PREDICTED ANNUAL CONCENTRATIONS 5KM FROM RUNWAY GEOMETRIC CENTER ($\mu g/m^3$)

AIR FORCE BASE	CO	RHC	NO_2	TSP	SO_2
DAVIS-MONTHAN	31.9	10.0	2.9	0.5	0.3
GRISSOM	7.7	2.4	.8	.1	.1
KELLY	39.5	4.0	.7	.3	.1
LANGLEY	15.4	2.1	.7	.2	.1
LUKE	35.4	5.7	1.6	.5	.3
MacDILL	8.5	1.9	1.0	.8	.1
McGUIRE	26.2	10.6	3.4	.5	.3
NELLIS	13.1	3.1	1.5	.3	.1
TINKER	6.9	2.4	.5	.2	.1
WILLIAMS	24.2	22.1	.5	.1	.2
Average concentration	20.9	6.4	1.4	0.4	0.2
% of primary NAAQS	N/A	N/A	.01%	.47%	.21%

The predicted annual concentration indices, tabulated in Table 3, are low for all pollutants which have annual standards specified. Levels averaged over all 10 bases are less than 1 percent of the National Ambient Air Quality Standards (NAAQS) for NO_2, TSP, and SO_2. Concentrations due to aircraft operations are never more than 3 percent of the NAAQS.

Application of a Modified Pollution Standards Index

AQAM short-term data were initially computed as hourly concentrations. Presenting these results proved cumbersome. Various isopleths, logscale graphs, etc., were tried but failed to produce easily comparable results for five different pollutants, 10 different air bases and many different downwind distances. To reduce this problem, concentrations were converted from units of micrograms per cubic meter to the 0500 segmented linear scale used in the recently developed Pollutant Standards Index (PSI) (Reference 6).

The PSI was developed by EPA to provide a simple, meaningful index to relate short-term pollutant concentrations to adverse health effects. To utilize the index, pollutant concentrations of each specie are converted to PSI values using up to five linear segments. Breakpoints between segments from 100 through 500 are based on the NAAQS, three levels of Federal Episode Criteria and the Significant Harm Levels. All breakpoints are broad indicators of "damage functions" resulting from many diverse effects of air pollution and should not be considered as precise boundaries.

While the PSI was not specifically designed for interpretation of modelling results, we have adapted it for this purpose. Short-term NAAQS have not been promulgated for NO_x. Therefore, the California standard of 470 $\mu g/m^3$ was used to establish a NO_x PSI of 100. Hydrocarbons are not part of the PSI since they are not directly related to health effects. There is, however, an indirect relationship since hydrocarbons can be precursors to photochemical oxidants under certain atmospheric situations. The NAAQS level of 160 $\mu g/m^3$ has been assigned a PSI value of 100 in this study for comparison of hydrocarbons with other pollutants. The associated PSI health effects terminology does not apply, however. Oxidants are not directly emitted from aircraft and can only be predicted from complex relationships outside the scope of this study.

The PSI averaging times were selected to coincide with those of the NAAQS. Durations of 1 hour for O_3, 1 hour for NO_2, 8 hours for CO, and 24 hours for SO_2 and TSP are specified. Conversion of the 1-hour AQAM predictions to the appropriate time periods was done with power laws (Reference 7). Single hour values were multiplied by 0.84, 0.68, and 0.59 to obtain approximately 3-hour (used for HC comparisons), 8-hour, and 24-hour averages, respectively. While this technique is not perfectly accurate since parameters such as atmospheric stability and downwind distances are not considered, the resulting errors should not affect overall conclusions.

Short-Term Air Quality Predictions

The AQAM Short-Term program and PSI scale were used to rank-order various air pollutant species. Meteorological inputs of wind speed, mixing depths and atmospheric stabilities were chosen for each location to predict the "worst case" concentrations on which the NAAQS are based. Results of these analyses are presented in Figure 2. Median values and arithmetic means are shown for each pollutant type. Reported levels are at receptors 5 km downwind from the runway geographic center. The potential for health effects of hydrocarbons cannot be determined from this figure. Descriptors used at various PSI levels were developed for oxidants but not for their hydrocarbon precursors. Nevertheless, a comparison of the relative differences between hydrocarbons and all pollutant species is valid. Hydrocarbons are clearly the most significant air pollutant in Figure 2. This finding is important due to the nature of the Air Force aircraft engine emission goals. These goals specify that THC and CO emissions will be below levels which result in an idle combustion efficiency of 98, 99, or 99.5 percent, depending on the engine type and vintage. This analysis strongly suggests that the design trade-offs to meet the efficiency goal should be weighted toward THC rather than CO control.

Predicted NO_2, CO, particulate matter, and SO_2 levels from aircraft sources are well below the PSI levels of expected health effects. Values in Figure 2 under "worst case" meteorological conditions produce levels less than 5 percent of the health effects levels. Values under more typical meteorological conditions would be much less than 1 percent of the health effect levels.

The relationship between PSI levels and downwind distance is shown in Figure 3. Data from all 10 bases were averaged to obtain these curves. The shapes of the curves are different since pollutants tend to be spatially distributed over different parts of the aircraft landing and takeoff cycle. For example, NO_x concentrations originate from a relatively small area near aircraft takeoffs but rapidly decrease due to crosswind dispersion. Other pollutants are distributed more uniformly over the aircraft emissions profile and show less decay with downwind distance. The relative significance of pollutants indicated by Figures 2 and 3 is (from most significant to least significant): hydrocarbons, oxides of nitrogen, particulate matter, carbon monoxide and sulfur oxides. This ordering can be used as a guide to future engine design priorities and control strategies.

For occasions where the PSI does not exceed 100, the aircraft values presented in this report linearly contribute to the total local PSI. When the PSI exceeds 100, the incremental contribution from aircraft must be recomputed from total concentrations because of the non-linearity of the PSI curves. However, because of the nature of these non-linearities, the contribution from aircraft would never be more than

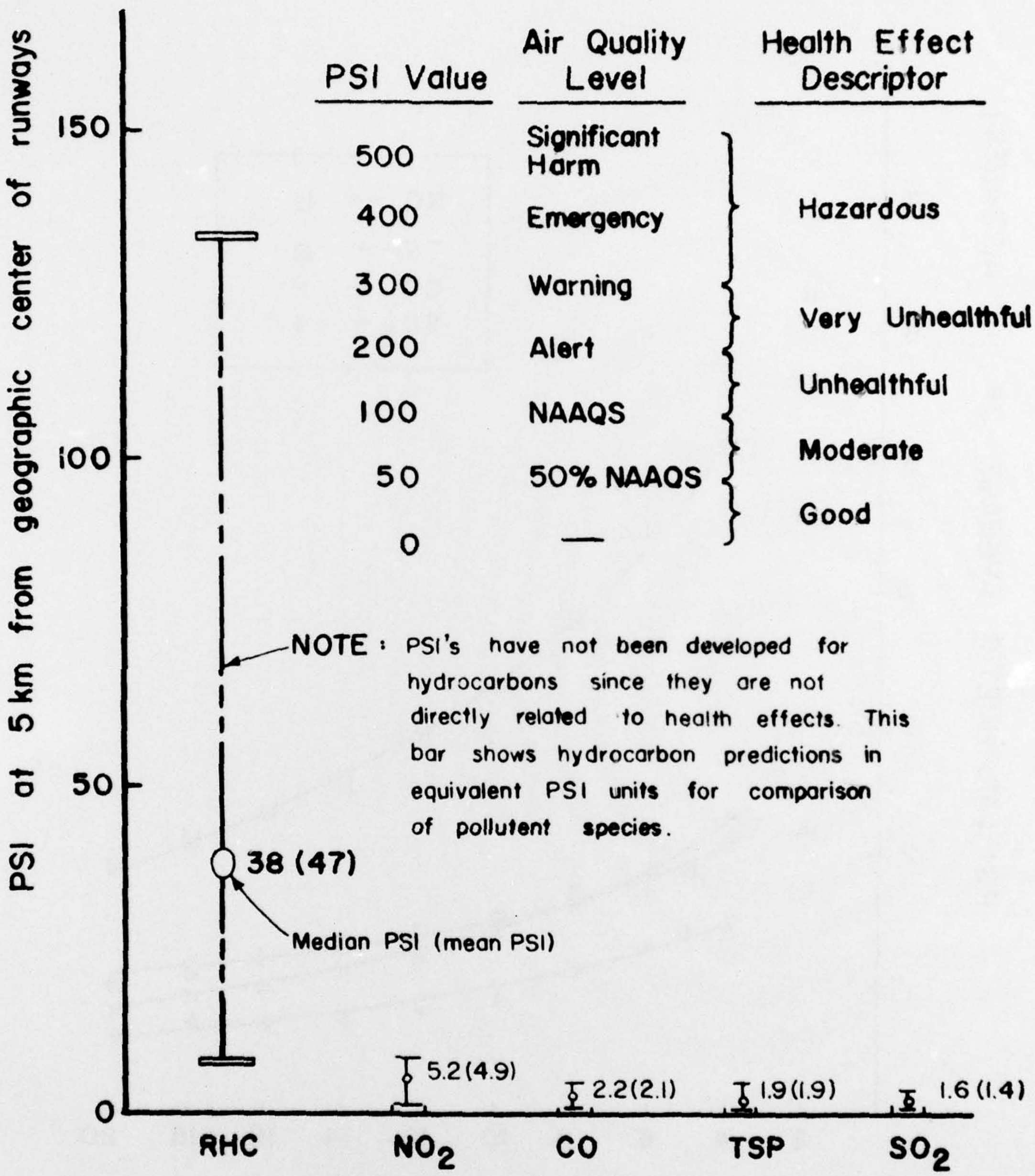

Figure 2. Relative Importance of Pollutant Species to Short Term Air Quality Impact Under Worst Case Meteorological Conditions

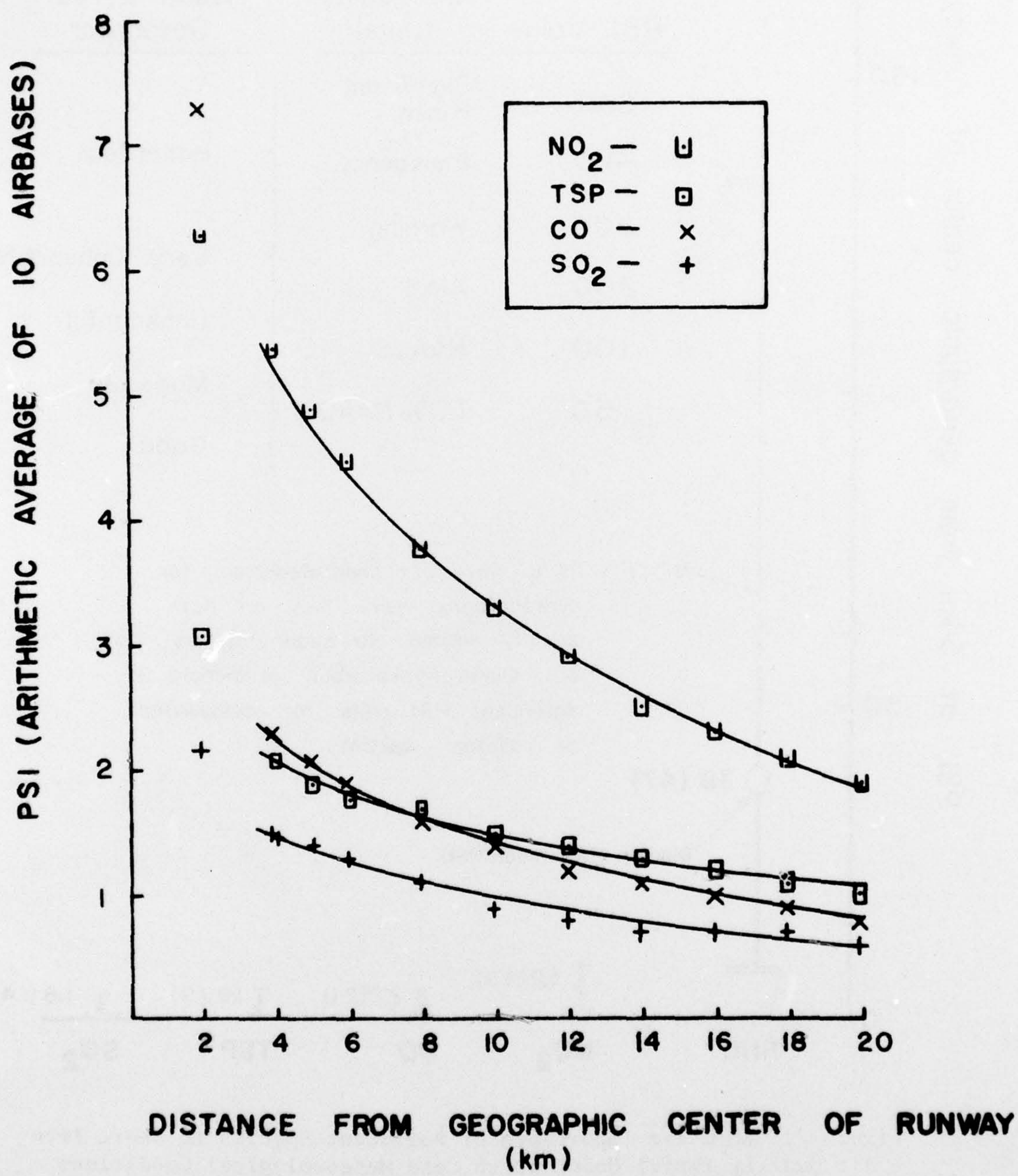

Figure 3. Decrease in PSI Levels with Downwind Distance

50 percent greater than presented here. The low PSI values for NO_2, CO, TSP, and SO_2 from Figures 2 and 3 suggest a minimal impact of current aircraft on air quality, even in areas of high urban pollution.

Conclusions

This work has analyzed the air quality impact of aircraft emissions by use of emission inventories and dispersion modelling. Annual aircraft emissions contributed an average of less than 1 percent to the regional emissions for the ten bases studied. This finding supports the general hypothesis that airports have a localized, but not a regional, impact on ambient air quality levels.

The EPA developed Pollutant Standards Index is a useful technique to relate air quality predictions to levels of health effects. Results do not indicate that significant environmental benefits can be derived from retrofitting current aircraft engines with controls for carbon monoxide, particulate matter, sulfur oxides or oxides of nitrogen. Aircraft contributions to PSI levels for carbon monoxide, particulate matter and sulfur dioxide are 2 percent or less of the PSI levels designated for initial health effects. Equivalent nitrogen dioxide levels are 5 percent. These percentages are the yearly maximums predicted at 5 km from the air bases. They would be much smaller under typical meteorological conditions and decrease rapidly at downwind distances greater than 5 km. Annual average pollutant concentration predictions also support this conclusion. Aircraft contributions are less than 1 percent of the NAAQS where annual concentrations are specified.

A rank-ordering of aircraft pollutants clearly indicates hydrocarbons to be the most significant relative to air quality standards. Turbine engine design criteria which involve trade-offs between hydrocarbon and carbon monoxide controls should therefore emphasize hydrocarbon reductions.

The actual impact of hydrocarbons from aircraft has not been determined. While fairly high values are predicted relative to hydrocarbon NAAQS, health effects would only result from products of complex photochemical reactions.

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